2. DRILLING MACHINE

2.1 Introduction

Drilling machine is one of the most important machine tools in a workshop. It was designed to produce a cylindrical hole of required diameter and depth on metal workpieces.

Though holes can be made by different machine tools in a shop, drilling machine is designed specifically to perform the operation of drilling and similar operations. Drilling can be done easily at a low cost in a shorter period of time in a drilling machine.

Drilling can be called as the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edges of a drill.

The cutting tool known as drill is fitted into the spindle of the drilling machine. A mark of indentation is made at the required location with a center punch. The rotating drill is pressed at the location and is fed into the work. The hole can be made upto a required depth.

2.2 Construction of a drilling machine

The basic parts of a drilling machine are a base, column, drillhead and spindle.

The base made of cast iron may rest on a bench, pedestal or floor depending upon the design. Larger and heavy duty machines are grounded on the floor. The column is mounted vertically upon the base. It is accurately machined and the table can be moved up and down on it. The drill spindle, an electric motor and the mechanism meant for driving the spindle at different speeds are mounted on the top of the column. Power is transmitted from the electric motor to the spindle through a flat belt or a ‘V’ belt.

2.3 Types of drilling machines

Drilling machines are manufactured in different types and sizes according to the type of operation, amount of feed, depth of cut, spindle speeds, method of spindle movement and the required accuracy.
The different types of drilling machines are:

- Portable drilling machine (or) Hand drilling machine
- Sensitive drilling machine (or) Bench drilling machine
- Upright drilling machine
- Radial drilling machine
- Gang drilling machine
- Multiple spindle drilling machine
- Deep hole drilling machine

**Portable drilling machine**

Portable drilling machine can be carried and used anywhere in the workshop. It is used for drilling holes on workpieces in any position, which is not possible in a standard drilling machine. The entire drilling mechanism is compact and small in size and so can be carried anywhere. This type of machine is widely adapted for automobile built-up work. The motor is generally universal type. These machines can accommodate drills from 12mm to 18 mm diameter. Portable drilling machines are operated at higher speeds.

**2.3.2 Sensitive drilling machine**

It is designed for drilling small holes at high speeds in light jobs. High speed and hand feed are necessary for drilling small holes. The base of the machine is mounted either on a bench or on the floor by means of bolts and nuts. It can handle drills up to 15.5mm of diameter. The drill is fed into the work purely by hand. The operator can sense the progress of the drill into the work because of hand feed. The machine is named so because of this reason. A sensitive drilling machine consists of a base, column, table, spindle, drillhead and the driving mechanism.

*A sensitive drilling machine is shown in Fig. 2.1.*

**Base**

The base is made of cast iron and so can withstand vibrations. It may be mounted on a bench or on the floor. It supports all the other parts of the machine on it.

**Column**

The column stands vertically on the base at one end. It supports the work table and the drill head. The drill head has drill spindle and the driving motor on either side of the column.
The table is mounted on the vertical column and can be adjusted up and down on it. The table has ‘T’-slots on it for holding the workpieces or to hold any other work holding device. The table can be adjusted vertically to accommodate workpieces of different heights and can be clamped at the required position.

**Drill head**

Drillhead is mounted on the top side of the column. The drill spindle and the driving motor are connected by means of a V-belt and cone pulleys. The motion is transmitted to the spindle from the motor by the belt. The pinion attached to the handle meshes with the rack on the sleeve of the spindle for providing the drill the required downfeed. There is no power feed arrangement in this machine. The spindle rotates at a speed ranging from 50 to 2000 r.p.m.
2.3.3 Upright drilling machine

The upright drilling machine is designed for handling medium sized workpieces. Though it looks like a sensitive drilling machine, it is larger and heavier than a sensitive drilling machine. Holes of diameter upto 50mm can be made with this type of machine. Besides, it is supplied with power feed arrangement. For drilling different types of work, the machine is provided with a number of spindle speeds and feed.

![Fig 2.2 Upright drilling machine](image-url)
There are two different types of upright drilling machines according to the cross-section of the column and they are

Round column section upright drilling machine
Box column section upright drilling machine

A round column section upright drilling machine is shown in Fig. 2.2.

The main parts of a upright drilling machine are: base, column, table and drillhead.

**Base**

Base is made of cast iron as it can withstand vibrations set by the cutting action. It is erected on the floor of the shop by means of bolts and nuts. It is the supporting member as it supports column and other parts on it. The top of the base is accurately machined and has ‘T’-slots. When large workpieces are to be held, they are directly mounted on the base.

**Column**

Column stands vertically on the base and supports the work table and all driving mechanisms. It is designed to withstand the vibrations set up due to the cutting action at high speeds.

**Table**

Table is mounted on the column and can be adjusted up and down on it. It is provided with ‘T’-slots for workpieces to be mounted directly on it. Table may have the following adjustments

Vertical adjustment obtained by the rack on the column and a pinion in the table
Circular adjustment about its own axis

After the required adjustments are made, the table is clamped in position.

**Drill head**

The drillhead is mounted on the top of the column. It houses the driving and feeding mechanism of the spindle. The spindle can be provided with hand or power feed. There are separate hand wheels for quick hand feed and sensitive hand feed. The handle is spring loaded so that the drill spindle is released from the work when the operation is over.
2.3.4 Radial drilling machine

The radial drilling machine is intended for drilling on medium to large and heavy workpieces. It has a heavy round column mounted on a large base. The column supports a radial arm, which can be raised or lowered to enable the table to accommodate workpieces of different heights. The arm, which has the drillhead on it, can be swung around to any position. The drill head can be made to slide on the radial arm. The machine is named so because of this reason. It consists of parts like base, column, radial arm, drillhead and driving mechanism. A radial drilling machine is illustrated in Fig. 2.3

![Fig 2.3 Radial drilling machine](image)

**Base**

The base is a large rectangular casting and is mounted on the floor of the shop. Its top is accurately finished to support a column at one end and the table at the other end. ‘T’-slots are provided on it for clamping workpieces.
Column

The column is a cylindrical casting, which is mounted vertically at one end of the base. It supports the radial arm and allows it to slide up and down on its face. The vertical adjustment of the radial arm is effected by rotating a screw passing through a nut attached to the arm. An electric motor is mounted on the top of the column for rotating the elevating screw.

Radial arm

The radial arm is mounted on the column parallel to the base and can be adjusted vertically. The vertical front surface is accurately machined to provide guideways for the drillhead. The drillhead can be adjusted along these guideways according to the location of the work. In some machines, a separate motor is provided for this movement. The arm may be swung around the column. It can also be moved up and down to suit workpieces of different heights.

Drillhead

The drillhead is mounted on the radial arm and houses all mechanism for driving the drill at different speeds and at different feed. A motor is mounted on top of the drillhead for this purpose. To adjust the position of drill spindle with respect to the work, the drillhead may be made to slide on the guideways of the arm. The drillhead can be clamped in position after the spindle is properly adjusted.

Universal radial drilling machine

It is a machine in which the spindle can be swiveled to any required angle in vertical and horizontal positions.

2.3.5. Gang drilling machine

Gang drilling machine has a long common table and a base. Four to six drillheads are placed side by side. The drillheads have separate driving motors. This machine is used for production work.

A series of operations like drilling, reaming, counterboring and tapping may be performed on the work by simply shifting the work from one position to the other on the work table. Each spindle is set with different tools for different operations.

*Fig.2.4 shows a gang drilling machine.*
2.3.6 Multiple spindle drilling machine

This machine is used for drilling a number of holes in a workpiece simultaneously and for reproducing the same pattern of holes in a number of identical pieces. A multiple spindle drilling machine also has several spindles. A single motor using a set of gears drives all the spindles. All the spindles holding the drills are fed into the work at the same time. The distances between the spindles can be altered according to the locations where holes are to be drilled. Drill jigs are used to guide the drills.

2.3.7 Deep hole drilling machine

A special machine and drills are required to drill deeper holes in barrels of gun, spindles and connecting rods. The machine designed for this purpose is known as deep hole drilling machine. High cutting speeds and less feed are necessary to drill deep holes. A non-rotating drill is fed slowly into the rotating work at high speeds. Coolant should be used while drilling in this machine. There are two different types of deep hole drilling machines

1. Vertical type  2. Horizontal type

2.4 Size of a drilling machine

Drilling machines are specified according to their type.

A portable drilling machine is specified by the maximum diameter of the drill that it can handle.
The size of the sensitive and upright drilling machines are specified by the size of the largest workpiece that can be centered under the spindle. It is slightly smaller than twice the distance between the face of the column and the axis of the spindle.

Particulars such as maximum size of the drill that the machine can operate, diameter of the table, maximum travel of the spindle, numbers and range of spindle speeds and feeds available, morse taper number of the drill spindle, floor space required, weight of the machine, power input are also needed to specify the machine completely. The size of the radial drilling machine is specified by the diameter of the column and length of the radical arm.

2.5 Drill spindle assembly

A drill spindle assembly is illustrated in Fig. 2.5. The drill spindle is a vertical shaft, which holds the drill. A long keyway is cut on the spindle and a sliding key connects it with a bevel gear or a stepped cone pulley. It receives motion from the driving motor. The spindle rotates within a non-rotating sleeve known as quill. The spindle and the sleeve are connected by a thrust bearing.

![Fig 2.5 Drill spindle](image-url)
Rack teeth are cut on the outer surface of the quill. The sleeve (quill) may be moved up and down by rotating a pinion which meshes with the rack. This movement is given to the spindle for providing the required feed. As there is a long keyway on top of the spindle, it is connected to the driving mechanism even during the feed movement.

A morse taper hole is provided at the lower end of the spindle. It is useful in accommodating a taper shank drill. The tang of the drill fits into a slot provided at the end of the taper hole. To remove the drill from the spindle a drift may be pushed through the slot.

The spindle drive is obtained in three methods. They are:

- Step cone pulley drive
- Step cone pulley with back gear arrangement
- Gear box drive

**Work holding devices**

The work should be held firmly on the machine table before performing any operation on it. As the drill exerts very high quantity of torque while rotating, the work should not be held by hand. If the workpiece is not held by a proper holding device, it will start rotating along with the tool causing injuries to the operator and damage to the machine.

The devices used for holding the work in a drilling machine are

- Drill vise
- ‘T’ - bolts and clamps
- Step block
- V - block
- Angle plate
- Drill jigs

**Drill vise**

Vise is one of the important devices used for holding workpieces on a drilling machine table. The work is clamped in a vise between a fixed jaw and a movable jaw.

Parallel blocks are placed below the work so that the drill may completely pass through the work without damaging the table. Different types of vises are used for holding different types of work and for performing different operations.
The different types of vises are

- Plain vise
- Swivel vise
- Tilting vise
- Universal vise

_A plain vise is shown in Fig. 2.6._

![Fig 2.6 Drill vice](image)

**2.6.2 ‘T’ - bolts and clamps**

The workpieces can be held directly on the machine table by means of ‘T’ - bolts and clamps. The top of the machine table has ‘T’ - slots into which ‘T’ - bolts may be fitted. The bolts of diameter 15 to 20mm are used. The clamps are made of mild steel. ‘T’ - bolts pass through a central hole on the clamp. The clamp is made to rest horizontally on the work surface by placing a suitable step block at the other end of the work.

Some of the common types of clamps are: Plain slot clamp, goose-neck clamp and finger clamp. _Fig. 2.7 illustrates ‘T’ - bolt and a clamp._

![Fig 2.7 ‘T’ bolt & clamp](image)
2.6.3 Step blocks

The step blocks are used in combination with ‘T’ - bolts and clamps for holding the work directly on the table. The step block supports the other end of the clamp. Workpieces of different heights are held by leveling the clamp on different steps of the step block. Fig. 2.8 illustrates a step block.

2.6.4 ‘V’ - block

‘V’ - blocks are used for holding cylindrical workpieces. The work may be supported on two or three ‘V’ - blocks according to the length of the work. The work is held on the ‘V’ groove and is clamped by straps and bolts. They are made of cast iron or steel and are accurately machined. Fig. 2.9 shows the use of a ‘V’ - block.

2.6.5 Angle plate

Angle plates have two faces at right angle to each other and are made of cast iron. It resembles the English alphabet ‘L’. All the sides of a angle plate are machined accurately. Slots and holes are provided on both the faces of the angle plate. Work is clamped on one of its faces by means of bolts and nuts. The use of an angle plate is shown in Fig. 2.10
2.6.6 Drill Jig

Drill jigs are used in mass production process. A jig is specially designed to hold the work securely and to guide the tool at any desired position. Holes may be drilled at the same relative positions on each of the identical workpieces.

The work is clamped and removed easily. The cost of making a drill jig is more but a low order of skill is sufficient to work with a drill jig. Fig 2.11 illustrates a drill jig.

Different types of drill jigs are
1. Plate jig
2. Channel jig
3. Diameter jig
4. Box jig
5. Indexing jig.
2.7 Tools used in a drilling machine

Different tools are used for performing different types of operations. The most commonly used tools in a drilling machine are

- Drill
- Reamer
- Counterbore
- Countersink
- Tap

**Drill**

A drill is a tool used to originate a hole in a solid material. A helical groove known as ‘flute’ is cut along the length of the drill.

Different types of drills are
- Flat Drill
- Straight fluted drill
- Twist drill
- Centre drill

Twist drills are the type generally used in shop work. They are made of High speed steel (HSS) or High carbon steel.

There are two types of twist drills namely (i) Straight shank twist drill and (ii) Taper shank twist drill. The diameter of the straight shank drill ranges from 2 to 16mm. Taper shanks are provided on drills of larger diameter.

**2.7.2 Reamer**

The tool used for enlarging and finishing a previously drilled hole is known as a reamer. It is a multi tooth cutter and removes smaller amount of material. It gives a better finish and accurate dimension.

**2.7.3 Counterbore**

A Counterbore is a multi tooth cutting tool used for enlarging the top of the previously machined hole. It has three or four cutting teeth.

The flutes on them may be straight or helical. Straight fluted tools are used for machining softer materials like brass and aluminium and for short depth of cut. Helical fluted counterbores are used for longer holes.
2.7.4 Countersink

A countersink has cutting edges on its conical surfaces. It has a similar construction of a counterbore except for the angle of the cutting edges. The angle of countersinks will generally be 60°, 82° or 90°. It is used for enlarging the top of the holes conically.

2.7.5 Tap

A tap has threads like a bolt. It has three to four flutes cut across the threads. It can cut threads on the inside of a hole. The flutes on the threads form the cutting edges. It is a multi-point cutting tool. It will dig into the walls of the hole as the lower part of the tap is slightly tapered. The shank of the tap is square shaped to enable it to be held by a tap wrench.

2.7.6 Twist drill nomenclature

Axis

It is the longitudinal centerline of the drill running through the centres of the tang and the chisel edge.

Body

It is the part of the drill from its extreme point to the commencement of the neck, if present. Otherwise, it is the part extending up to the commencement of the shank. Helical grooves are cut on the body of the drill.

Shank

It is the part of the drill by which it is held and driven. It is found just above the body of the drill. The shank may be straight or taper. The shank of the drill can be fitted directly into the spindle or by a tool holding device.

Tang

The flattened end of the taper shank is known as tang. It is meant to fit into a slot in the spindle or socket. It ensures a positive drive of the drill.

Neck

It is the part of the drill, which is diametrically undercut between the body and the shank of the drill. The size of the drill is marked on the neck.

Point

It is the sharpened end of the drill. It is shaped to produce lips, faces, flanks and chisel edge.
Lip

It is the edge formed by the intersection of flank and face. There are two lips and both of them should be of equal length. Both lips should be at the same angle of inclination with the axis (59°).

Land

It is the cylindrically ground surface on the leading edges of the drill flutes adjacent to the body clearance surface. The alignment of the drill is maintained by the land. The hole is maintained straight and to the right size.
Flutes

The grooves in the body of the drill are known as flutes. Flutes form the cutting edges on the point. It allows the chips to escape and make them curl. It permits the cutting fluid to reach the cutting edges.

Angles

Chisel edge angle

The obtuse angle included between the chisel edge and the lip as viewed from the end of the drill. It usually ranges from 120° to 135°.

Helix angle or rake angle

The helix or rake angle is the angle formed by the leading edge of the land with a plane having the axis of the drill. If the flute is straight, parallel to the drill axis, then there would be no rake. If the flute is right handed, then it is positive rake and the rake is negative if it is left handed. The usual value of rake angle is 30° or 45°.

Point angle

This is the angle included between the two lips projected upon a plane parallel to the drill axis and parallel to the two cutting lips. The usual point angle is 118°. When hard alloys are drilled the value increases.

Lip clearance angle

The angle formed by the flank and a plane at right angles to the drill axis. The angle is normally measured at the periphery of the drill. The lip clearance angle ranges from 12° to 15°.

2.8 Tool holding devices

Different tools are used for performing different operations. They are fitted into the drill spindle by different methods. They are

By directly fitting in the spindle
By a sleeve
By a socket
By a chuck
Tapping attachment
2.8.1 Spindle

Almost all drilling machines have their spindle bored out to a standard taper(1:20) to receive the taper shank of the tool. While fitting the tool, the shank of the drill (or any other tool) is forced into the tapered hole and the tool is gripped by friction. The tool may be rotated with the spindle by friction between the tapered surface and the spindle. But to ensure a positive drive, the tang of the tool fits into a slot at the end of the taper hole. The tool may be removed by pressing a tapered wedge known as drift into the slotted hole of the spindle.

2.8.2 Sleeve

The drill spindle is suitable for holding only one size of tool shank. If the shank of the tool is smaller than the taper in the spindle hole, a taper sleeve is used. The outside taper of the sleeve conforms to the spindle taper and the inside taper holds the shanks of the smaller size tools. The sleeve has a flattened end or tang which fits into the slot of the spindle. The tang of the tool fits into a slot provided at the end of the taper hole of the sleeve. Different sizes of tool shanks may be held by using different sizes of sleeve. In order to remove the drill from the spindle, the drill along with the sleeve is removed with the help of a drift. The drill is then removed from the sleeve by the same method.

*Fig. 2.13 illustrates a sleeve.*
2.8.3 Socket

Drill sockets are much longer in size than the drill sleeves. A socket consists of a solid shank attached to the end of a cylindrical body. The taper shank of the socket conforms to the taper of the drill spindle and fits into it. The body of the socket has a tapered hole larger than the drill spindle taper into which the taper shank of any tool may be fitted. The tang of the socket fits into slot of the spindle and the tang of the tool fits slot of the socket. *Fig. 2.14 illustrates a socket.*

2.8.4 Drill chuck

This type of chuck is particularly adapted for holding tools having straight shanks. The drill chuck has a taper shank which fits into the taper hole of the spindle. The jaws fitted in the body of the chuck holds the straight shank drills. *Fig. 2.15 illustrates a drill chuck.*

2.8.5 Tapping attachment

The tapping attachment is used to hold the tool known as ‘tap’. It serves as a flexible connection between the spindle and the tap. The taper shank of the attachment is fitted into the drill spindle. The tap is fitted at the bottom of the attachment. The tap is fed into the specific hole by the spindle, rotating it in clockwise direction. After the threads are cut, the spindle is released from the hole. The bottom of the attachment rotates in anti-clockwise direction causing no damage to the tapped hole. Tapping attachments are used during production work. *Fig. 2.16 illustrates a tapping attachment.*
2.9 Drilling machine operations

Though drilling is the primary operation performed in a drilling machine, a number of similar operations are also performed on holes using different tools. The different operations that can be performed in a drilling machine are:

- Drilling
- Reaming
- Boring
- Counterboring
- Countersinking
- Spot facing
- Tapping
- Trepanning

Drilling

Drilling is the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edge of a cutting tool called drill. Drilling is one of the simplest methods of producing a hole. Drilling does not produce an accurate hole in a workpiece. The internal surface of the hole generated by drilling becomes rough and the hole is always slightly oversize due to vibration of the spindle and the drill. A hole made by a drill of size 12mm will measure approximately upto 12.125mm and by a drill of size 22mm will measure upto 22.5mm. **Fig. 2.17 illustrates drilling operation.**
2.9.2 Reaming

The size of hole made by drilling may not be accurate and the internal surface will not be smooth. Reaming is an accurate way of sizing and finishing a hole which has been previously drilled by a multi point cutting tool known as reamer. The surface obtained by reaming will be smoother and the size accurate. The speed of the spindle is made half that of drilling. Reaming removes very small amount of metal (approx 0.375 mm). In order to finish a hole and bring it to the accurate size, the hole is drilled slightly undersize. *Fig. 2.18* illustrates reaming operation.

2.9.3 Boring

Boring is the operation enlarging the diameter of the previously made hole. It is done for the following reasons.

To enlarge a hole by means of an adjustable cutting tool. This is done when a suitable sized drill is not available or the hole diameter is so large that is cannot be ordinarily drilled.

To finish a hole accurately and bring it to the required size
To machine the internal surface of the hole already produced in casting
To correct out of roundness of the hole
To correct the location of the hole as the boring tool follows independent path with respect to the hole
Boring tool is a tool with only one cutting edge. The tool is held in a boring bar which has a taper shank to fit into the spindle or a socket. For perfectly finishing a hole, the job is drilled undersize slightly. Boring operation in some precise drilling machine is performed to enlarge the holes to an accuracy of 0.00125mm. The spindle speed during boring should be adjusted to be lesser than that of reaming. *Fig. 2.19 illustrates boring operation.*

**Fig 2.19 Boring**

### 2.9.4 Counterboring

Counterboring is the operation of enlarging the end of the hole cylindrically. The enlarged hole forms a square shoulder with the original hole. This is necessary in some cases to accommodate the heads of bolts, studs and pins. The tool used for counterboring is known as counterbore.

The counterbores are made with cutting edges which may be straight or spiral. The cutting speed for counterboring is atleast 25% lesser than that of drilling.

**Fig 2.20 Counterboring**
2.9.5 Countersinking

Countersinking is the operation of making a cone shaped enlargement at the end of the hole. The included angle of the conical surface may be in the range of 60° to 90°. It is used to provide recess for a flat headed screw or a counter sunk rivet fitted into the hole. The tool used for counter sinking is known as a countersink. It has multiple cutting edges on its conical surface. The cutting speed for countersinking is 25% lesser than that of drilling.

Fig. 2.21 illustrates countersinking operation.

![Countersinking](image)

2.9.6 Spot facing

Spot facing is the operation of smoothing and squaring the surface around a hole. It is done to provide proper seating for a nut or the head of a screw. A counterbore or a special spot facing tool may be employed for this purpose.

Fig. 2.22 illustrates spot facing operation.

![Spotfacing](image)
2.9.7 Tapping

Tapping is the operation of cutting internal threads by means of a cutting tool called ‘tap’. Tapping in a drilling machine may be performed by hand or by power. When the tap is screwed into the hole, it removes metal and cuts internal threads which will fit into external threads of the same size. Fig. 2.23 illustrates tapping operation.

![Fig 2.23 Tapping](image)

2.9.8 Trepanning

Trepanning is the operation of producing a hole in sheet metal by removing metal along the circumference of a hollow cutting tool. Trepanning operation is performed for producing large holes. Fewer chips are removed and much of the material is saved while the hole is produced. The tool may be operated at higher speeds. The speed depends upon the diameter of the hole to be made. The tool resembles a hollow tube having cutting edges at one end and a solid shank at the other to fit into the drill spindle.

![Fig 2.24 Trepanning](image)
2.10 Cutting speed, Feed & Depth of cut

2.10.1 Cutting speed

Speed in general refers to the distance a point travels in a particular period of time. The cutting speed in a drilling operation refers to the peripheral speed of a point on the cutting edge of the drill. It is usually expressed in meters per minute. The cutting speed (v) may be calculated as

\[ \text{Cutting speed (C.S)} = \frac{\pi dn}{1000} \text{ m per min} \]

Where

- ‘d’ - is the diameter of the drill in mm, and ‘n’ - is the speed of the drill spindle in r.p.m.

The cutting speed of a drill depends, as in other machining processes, upon several factors like the cutting tool material, the kind of material being drilled, the quality of surface finish desired, the method of holding the work, the size, type and rigidity of the machine.

Example

A drill of diameter 20mm makes a hole on a steel part at a cutting speed of 25m/ min. Find out the spindle speed.

\[ \frac{\pi dn}{1000} = 25 \]

\[ \frac{\pi x 20 x n}{1000} = 25 \]

or \[ n = \frac{25 \times 1000}{\pi x 20} \]

Spindle speed, \( n = 398 \text{ r.p.m} \)

2.10.2 Feed

The feed of a drill is the distance the drill moves into the work at each revolution of the spindle. It is expressed in millimeters. The feed may also be expressed as feed per minute. The feed per minute may be defined as the axial distance moved by the drill into the work per minute. Feed depends upon factors like the material to be drilled, the rigidity of the machine, power, depth of the hole and the type of finish required.

2.10.3 Depth of cut

The depth of cut in drilling is equal to one half of the drill diameter. If ‘d’ is the diameter of the drill, the depth of cut (\( t \)) \( t = d/2 \text{ mm} \).
4. GRINDING MACHINE

4.1 Introduction

Grinding is a metal cutting operation like any other process of machining removing metal in comparatively smaller volume. The cutting tool used is an abrasive wheel having many numbers of cutting edges. The machine on which grinding the operation is performed is called a grinding machine.

Grinding is done to obtain very high dimensional accuracy and better appearance. The accuracy of grinding process is 0.000025mm. The amount of material removed from the work is very less.

4.2 Types of grinding machines

According to the accuracy of the work to be done on a grinding machine, they are classified as

- Rough grinding machines
- Precision grinding machines

**Rough grinding machines**

The rough grinding machines are used to remove stock with no reference to the accuracy of results. Excess metal present on the cast parts and welded joints are removed by rough grinders. The main types of rough grinders are

- Hand grinding machine
- Bench grinding machine
- Floor stand grinding machine
- Flexible shaft grinding machine
- Swing frame grinding machine
- Abrasive belt grinding machine
4.2.2 Precision grinding machines

Precision grinders are used to finish parts to very accurate dimensions. The main types of precision grinders are:

- Cylindrical grinding machines
- Internal grinding machines
- Surface grinding machines
- Tool and cutter grinding machines
- Special grinding machines

**Cylindrical grinding machine**

Cylindrical grinders are generally used to grind external surfaces like cylinders, taper cylinders, faces and shoulders of work. There are two types of cylindrical grinding machines and they are:

- External cylindrical grinding machines
- Internal cylindrical grinding machines

![Cylindrical grinding machine diagram](image)

**Fig 4.1 Cylindrical grinding machine**

**External cylindrical grinding machine**

Cylindrical centre type grinders are intended primarily for grinding plain cylindrical parts. *Fig.4.1 illustrates a cylindrical grinder.*
Base

The base is made of cast iron and rests on the floor. It supports the parts mounted on it. The top of the base is accurately machined and provides guideways for the table to slide on. The base contains the table driving mechanisms.

Tables

The tables are mounted on top of the base. There are two tables namely lower table and upper table. The lower table slides on the guideways on the bed. It can be moved by hand or by power within required limits.

The upper table can be swiveled upto ±10° and clamped in position. Adjustable dogs are clamped in longitudinal slots at the side of the lower table. They are set up to reverse the table at the end of the stroke.

Headstock

The headstock is situated at the left side of upper table. It supports the workpiece by means of a centre and drives it by means of a dog. It may hold and drive the workpiece in a chuck. It houses the mechanism meant for driving the work. The headstock of a universal grinding machine can be swiveled to any required angle.

Tailstock

The tailstock is situated at the right side of the table. It can be adjusted and clamped in various positions to accommodate different lengths of workpieces.

Wheelhead

The wheelhead may be moved at right angles to the table ways. It is operated by hand or by power to feed the wheel to the work. The wheelhead carries a grinding wheel.

Its driving motor is mounted on a slide at the top and rear of the base. The grinding wheel rotates at about 1500 to 2000 r.p.m.

Internal cylindrical grinding machines

Internal grinders are useful in grinding cylindrical holes and taper holes.

4.2.4 Surface grinding machines

Surface grinding machines are employed to finish plain or flat surfaces horizontally, vertically or at any angle.
There are four different types of surface grinders. They are:

- Horizontal spindle and reciprocating table type
- Horizontal spindle and rotary table type
- Vertical spindle and reciprocating table type
- Vertical spindle and rotary table type

**Horizontal spindle surface grinding machine**

The majority of surface grinders are of horizontal spindle type. In the horizontal type of the machine, grinding is performed by the abrasives on the periphery of the wheel. Though the area of contact between the wheel and the work is small, the speed is uniform over the grinding surface and the surface finish is good. The grinding wheel is mounted on a horizontal spindle and the table is reciprocated to perform grinding operation.

**Base**

The base is made of cast iron. It is a box like casting which houses all the table drive mechanisms. The column is mounted at the back of the base which has guideways for the vertical adjustment of the wheelhead.

**Saddle**

Saddle is mounted on the guideways provided on the top of the base. It can be moved at cross towards or away from the column.

**Table**

The table is fitted to the carefully machined guideways of the saddle. It reciprocates along the guideways to provide the longitudinal feed. The table is provided with ‘T’- slots for clamping workpieces directly on the table or for clamping grinding fixtures or magnetic chuck.

**Wheelhead**

An electric motor is fitted on the wheelhead to drive the grinding wheel. The wheelhead is mounted on the guideways of the column, which is secured to the base. It can be raised or lowered with the grinding wheel to accommodate workpieces of different heights and to set the wheel for depth of cut.

*Fig.4.2 illustrates a horizontal spindle surface grinding machine.*
Vertical spindle surface grinding machine

The face or sides of the wheel are used for grinding in the vertical type surface grinders. The area of contact is large and stock can be removed quickly. But a criss-cross pattern of grinding scratches are left on the work surface. Considering the quality of surface finish obtained, the horizontal spindle type machines are widely used.

The grinding wheel is mounted on the vertical spindle of the machine. The work is held on the table and grinding is done.

The base of the machine is a box like casting. The base is very similar to the one of the horizontal spindle type. It houses all the table drive mechanisms.
The table is mounted on the base on top of which a magnetic chuck is mounted. A grinding wheel is mounted on the wheelhead which slides vertically on the column. The table is made to reciprocate or rotate to bring the work surface below the grinding wheel to perform grinding.

Fig.4.3 illustrates a vertical spindle surface grinding machine.

Fig 4.3 Vertical spindle surface grinder

4.2.5 Tool and cutter grinding machines

Tool and cutter grinders are used mainly to sharpen the cutting edges of various tools and cutters. They can also do surface, cylindrical and internal grinding to finish jigs, fixtures, dies and gauges.

Base

The base of the machine gives rigidity and stability to the machine. It is bolted rigidly to the floor of the shop by bolts and nuts. It supports all the other parts of the machine. It is box type and houses all the mechanisms for the saddle movements.

Saddle

The saddle is mounted directly on the top of the base and slides over it. The column is mounted on the saddle. It can be moved up and down and swivelled to either side.
Table

The table resets and moves on a top base, which is mounted over the saddle. The table has two layers. The worktable is mounted on the sub table which has ‘T’ slots for mounting the work and attachments used on the machine. The worktable can be swiveled while grinding tapers.

Headstock and tailstock

The headstock and tailstock are mounted on either side of the table. The workpieces are positioned between centres and driven exactly as in a cylindrical grinder.

Wheelhead

The wheelhead is mounted on a column on the back of the machine. It can be swiveled and positioned in the base for different set-up. A straight wheel and a cup wheel are mounted on either sides of the wheelhead. Fig.4.4 illustrates a tool and cutter grinding machine.

![Fig 4.4 Tool and cutter grinder](image)

4.3 Size of a grinding machine

The size of a grinding machine is specified according to the size of the largest workpiece that can be mounted on the machine.

The cylindrical centre type grinding machine is specified by the diameter and length of the largest workpiece the machine can accommodate between centers.
The internal centre type grinder is specified by the diameter of workpiece that can be swung and the maximum length of the stroke of the grinding wheel.

The reciprocating table type surface grinders are specified by the table area and the maximum height of the grinding wheel from the table surface. The rotary table type surface grinder is specified by the diameter of the chuck or table. A tool and cutter grinder is specified further by the maximum size of tool that can be sharpened and dressed.

4.4 Centreless grinding

Centreless grinding is a method of grinding external cylindrical, tapered and formed surfaces on workpieces that are not held and rotated between centres or in chucks. There are two types of centreless grinding and they are

1. External centreless grinding

2. Internal centreless grinding

4.4.1 External centreless grinding

Two wheels - a grinding and a regulating wheel are used in external centreless grinding. Both these wheels are rotated in the same direction. The work is placed upon the work rest and rotated between the wheels. The feed movement of the work along its axis past the grinding wheel is obtained by tilting the regulating wheel at a slight angle from the horizontal. An angular adjustment of 0 to 10 degrees is provided in the machine for this purpose. *Fig. 4.5 shows centreless grinding operation.*
4.4.2 Internal centreless grinding

The principle of external centreless grinding is applied to internal centreless grinding also. Grinding is done on the inner surfaces of the holes. In internal centreless grinding, the work is supported by three rolls - a regulating roll, a supporting roll and a pressure roll. The grinding wheel contacts the inside surface of the workpiece directly opposite the regulating roll. The distance between the contours of these two wheels is the wall thickness of the work. Fig. 4.6 shows internal centreless grinding operation.

![Internal Centreless Grinding Diagram](image)

**Fig 4.6 Internal centreless grinding**

**Advantages of centreless grinding**

As the workpiece is supported throughout the entire length, grinding is done very accurately.

- Small, slender and fragile workpieces can be ground easily.
- No chucking or mounting of the work on mandrels & other holding devices are required.
- As the process is continuous, it is best adapted for production work.
- The size of the work can easily be controlled.
- A low order of skill is needed in the operation of the machine.
Diadvantages of centreless grinding

In hollow work, there is no certainty that the outer diameter will be concentric with the inside diameter.
Works having multiple diameters are not handled easily.

4.5 Grinding machine operations

The process of grinding is the operation of removing excess material from metal parts by a grinding wheel made of hard abrasives. The following operations are generally performed in a grinding machine.

Cylindrical grinding
Taper grinding
Gear grinding
Thread grinding

Cylindrical grinding

Cylindrical grinding is performed by mounting and rotating the work between centres in a cylindrical grinding machine. The work is fed longitudinally against the rotating grinding wheel to perform grinding. The upper table of the grinding machine is set at 0° during the operation.

4.5.2 Taper grinding

Taper grinding on long workpieces can be done by swiveling the upper table. If the workpiece is short, the wheelhead may be swiveled to the taper angle. Another method of grinding external taper is to true the face of the grinding wheel by a diamond tool dresser to the required angle. In this case, the table and the wheelhead are not swiveled.

4.5.3 Gear grinding

The teeth of gears are ground accurately on gear grinding machines for their shape. Gear grinding is done by the generating process or by using a form grinding wheel.

The generating process makes use of two saucer shaped grinding wheels. These wheels are used to grind two faces of successive teeth.

The forming process makes use of formed wheels to grind a tooth at a time. This is a very precise method of performing gear grinding.
4.5.4 Thread grinding

Thread grinding machines are used to grind threads accurately. The grinding wheel itself is shaped to the thread profile. These formed grinding wheels have one or multi threads on them.

4.5.5 Wet grinding and dry grinding

Wet grinding

The method of spreading a good quantity of coolant over the work surface and wheel faces during grinding is known as ‘wet grinding’. Soda water is used as a coolant. The process of grinding generates high amount of heat generally about 2000°C. Various properties of the work material change due to the heat. In order to reduce the heat generated during grinding, coolant is used. Wet grinding promotes long wheel life and better look of the ground surface. Coolant is pumped from the tank through pipelines.

Dry grinding

Dry grinding is the method of doing grinding operation without applying coolant. Dry grinding produces undesirable effects on work surfaces. It leads to burring & discoloration of work surfaces. The cutting edges of the grinding wheel lose their cutting capacity. So, dry grinding should better be avoided.

4.6 Grinding wheel

A grinding wheel is a multi-tooth cutter made up of many hard particles known as abrasives having sharp edges. The abrasive grains are mixed with a suitable bond, which acts as a matrix to manufacture grinding wheels.

According to construction, grinding wheels are classified under three categories.

Solid grinding wheels
Segmented grinding wheels
Mounted grinding wheels

Abrasives

Abrasives are used for grinding and polishing operations. It should have uniform physical properties of hardness, toughness and resistance to fracture. Abrasive may be classified into two principal groups.

Natural abrasives
Artificial abrasives
4.6.2 Natural abrasives

The natural abrasives are obtained from the Earth’s crust. They include sandstone, emery, corundum and diamond.

Sandstone is used as abrasive to grind softer materials only.

Emery is natural alumina. It contains aluminium oxide and iron oxide. Corundum is also a natural aluminium oxide. It contains greater percentage of aluminium oxide than emery. Both emery and corundum have a greater hardness and abrasive action than sandstone.

Diamond is the hardest available natural abrasive. It is used in making grinding wheels to grind cemented carbide tools.

4.6.3 Artificial abrasives

Artificial abrasives are of two types.

- Silicon carbide abrasives
- Aluminium oxide abrasives

Silicon carbide

Silicon carbide is manufactured from 56 parts of silica, 34 parts of powdered coke, 2 parts of salt and 12 parts of sawdust in a long rectangular electric furnace of the resistance type that is built of loose brick work. There are two types of silicon carbide abrasives - green grit and black grit.

Silicon carbide is next to diamond in the order of hardness. But it is not tough enough as aluminium oxide. It is used for grinding materials of low tensile strength such as cemented carbides, ceramic materials, grey brass, bronze, copper, aluminium, vulcanized rubber etc. This is manufactured under trade names of carborundum. It is denoted by the letter ‘S’.

Aluminium oxide

Aluminium oxide is manufactured by heating mineral bauxite, silica, iron oxide, titanium oxide, etc., mixed with ground coke and iron borings in arc type electric furnace.

Aluminium oxide is tough and not easily fractured, so it is better adapted to grinding materials of high tensile strength such as most steels, carbon steels, high speed steels, and tough bronzes. This is denoted by the letter ‘A’.
4.6.4 Types of bonds

A bond is an adhesive substance that is employed to hold abrasive grains together in the form of grinding wheels. There are several types of bonds. Different grinding wheels are manufactured by mixing hard abrasives with suitable bonds. The table containing the types of wheels manufactured using different types of bonds and their symbols is given below.

<table>
<thead>
<tr>
<th>Type of bond</th>
<th>Symbol</th>
<th>Grinding wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vitrified</td>
<td>V</td>
<td>Vitrified wheel</td>
</tr>
<tr>
<td>2. Silicate</td>
<td>S</td>
<td>Silicate wheel</td>
</tr>
<tr>
<td>3. Shellac</td>
<td>E</td>
<td>Elastic wheel</td>
</tr>
<tr>
<td>4. Resinoid</td>
<td>B</td>
<td>Resinoid wheel</td>
</tr>
<tr>
<td>5. Rubber</td>
<td>R</td>
<td>Vulcanised wheel</td>
</tr>
<tr>
<td>6. Oxychloride</td>
<td>O</td>
<td>Oxychloride wheel</td>
</tr>
</tbody>
</table>

4.6.5 Grain size, Grade and Structure

Grain size (Grit)

The grinding wheel is made up of thousands of abrasive grains. The grain size or grit number indicates the size of the abrasive grains used in making a wheel, or the size of the cutting teeth. Grain size is denoted by a number indicating the number of meshes per linear inch of the screen through which the grains pass when they are graded. There are four different groups of the grain size namely coarse, medium, fine and very fine. If the grit number is large, the size of the abrasive is fine and a small grit number indicates a large grain of abrasive.

- Coarse : 10, 12, 14, 16, 20, 24
- Medium : 30, 36, 46, 54, 60
- Fine : 80, 100, 120, 150, 180
- Very fine : 220, 240, 280, 320, 400, 500, 600
Grade

The grade of a grinding wheel refers to the hardness with which the wheel holds the abrasive grains in place. It does not refer to the hardness of the abrasive grains. The grade is indicated by a letter of the English alphabet. The term ‘soft’ or ‘hard’ refers to the resistance a bond offers to disruption of the abrasives. A wheel from which the abrasive grains can easily be dislodged is called soft whereas the one, which holds the grains more securely, is called hard. The grade of the bond can be classified in three categories.

- Soft: A B C D E F G H
- Medium: I J K L M N O P
- Hard: Q R S T U V W X Y Z

Structure

The relative spacing occupied by the abrasives and the bond is referred to as structure. It is denoted by the number and size of void spaces between grains. It may be ‘dense’ or ‘open’. Open structured wheels are used to grind soft and ductile materials. Dense wheels are useful in grinding brittle materials.

- Dense: 1 2 3 4 5 6 7 8
- Open: 9 10 11 12 13 14 15 or higher

4.6.6 Standard marking system of grinding wheels

The Indian standard marking system for grinding wheels has been prepared with a view of establishing a uniform system of marking of grinding wheels to designate their various characteristics.

- Prefix: Manufacturer’s abrasive type symbol
- First element (letter): Type of abrasive
- Second element (number): Size of abrasive
- Third element (letter): Grade of bond
- Fourth element (number): Structure of the grinding wheel
- Fifth element (letter): Type of bond
- Suffix: Manufacturer’s symbol
The meaning of the given marking on a grinding wheel

\[ w \ A \ 54 \ M \ 7 \ V \ 20 \]

- Manufacturer’s abrasive type symbol
- Type of abrasive - Aluminium oxide
- Size of abrasive - Medium
- Grade of bond - Medium
- Structure of the grinding wheel - Dense
- Type of bond - Vitrified
- Manufacturer’s symbol

4.6.7 Mounting of a grinding wheel

Great care must be taken in mounting the grinding wheels on the spindle because of high cutting speeds. The following points are important in connection with mounting of grinding wheel. *Fig. 4.7 shows mounting of a grinding wheel.*

1. All wheels should be inspected before mounting to make sure that they have not been damaged. The wheel is put on an arbor and is subjected to slight hammer blows. A clear, ringing, vibrating sound must be heard.
The wheel should not be forced on and they should have an easy fit on the spindle.

The hole of grinding wheel is mostly lined with lead. The lead liner bushes should not project beyond the side of wheels.

There must be a flange on each side of the wheel. The flange must be large enough to hold the wheel properly, at least the flange diameter must be equal to the half of the grinding wheel diameter. Both the flanges should be of same diameter.

The sides of the wheel and the flanges should be flat. Flanges contact the wheel only with the annular clamping area.

Washers of compressible materials such as cardboard, leather, rubber etc., not over mm thick should be fitted between the wheel and its flanges. The diameter of washers may be normally equal to the diameter of the flanges.

The inner flange should be keyed to the spindle, whereas the outer flange should have an easy sliding fit on the spindle so that it can adjust itself tightly to give a uniform bearing on the wheel and the compressible washers.

The nut should be tightened to hold the wheel firmly. Undue tightness is unnecessary and undesirable as excessive clamping strain is liable to damage the wheel.

The wheel guard should be placed and tightened before the machine is started.

After mounting the wheel, the machine is started. The grinding wheel should be allowed to idle for a period of about 10 to 15 minutes. Grinding wheels must be dressed and trued before any work can be started.

4.6.8 Glazing, Loading and Chattering

Glazing

It is the condition of the grinding wheel in which the cutting edges or the face of the wheel takes a glass-like appearance. Glazing takes place if the wheel is rotated at very high speeds and is made with harder bonds. Rotating the wheel at lesser speeds and using soft bonds are the remedies. The glazed wheels are dressed to have fresh, sharp cutting edges.

Loading

The wheel is loaded if the particles of the metal being ground adhere to the wheel. The openings or pores of the wheel face are filled up with the metal. It is caused by grinding a softer material or by using a very hard bonded wheels and running it very slowly. It may also take place if very deep cuts are taken by not using the right type of coolant.
Chattering

The wavy pattern of crisscross lines are visible on the ground surface some times. This condition is known as chattering. It takes place when the spindle bearings are not fitted correctly and because of the imbalance of the grinding wheel.

4.6.9 Dressing and truing of grinding wheels

Dressing

If the grinding wheels are loaded or gone out of shape, they can be corrected by dressing or truing of the wheels. Dressing is the process of breaking away the glazed surface so that sharp particles are again presented to the work. The common types of wheel dressers known as “Star” -dressers or diamond tool dressers are used for this purpose.

A star dresser consists of a number of hardened steel wheels on its periphery. The dresser is held against the face of the revolving wheel and moved across the face to dress the wheel surface. This type of dresser is used particularly for coarse and rough grinding wheels. Fig. 4.8 shows dressing by a star wheel dresser.

![Fig 4.8 Dressing of a grinding wheel (Star wheel method)](image)

For precision and high finish grinding, small industrial diamonds known as ‘bort’ are used. The diamonds are mounted in a holder. The diamond should be kept pointed down at an angle of 15° and a good amount of coolant is applied while dressing. Very light cuts only may be taken with diamond tools.

Fig. 4.9 shows dressing by a diamond tool dresser.
Truing

The grinding wheel becomes worn from its original shape because of breaking away of the abrasive and bond. Sometimes the shape of the wheel is required to be changed for form grinding. For these purposes the shape of the wheel is corrected by means of diamond tool dressers. This is done to make the wheel true and concentric with the bore or to change the face contour of the wheel. This is known as truing of grinding wheels.

Diamond tool dressers are set on the wheels at 15° and moved across with a feed rate of less than 0.02mm. A good amount of coolant is applied during truing.

4.6.10 Balancing of grinding wheels

Grinding wheels rotate at high speeds. The density and weight should be evenly distributed throughout the body of the wheel. If it is not so, the wheel will not rotate with correct balance.

The grinding wheels are balanced by mounting them on test mandrels. The wheel along with the mandrel is rolled on knife edges to test the balance and corrected.
4.7 Cutting speed, feed and depth of cut

4.7.1 Cutting speed

Cutting speed of a grinding process is the relative speed of the grinding wheel and the workpiece. It is expressed in m/sec.

The cutting speed of the wheel is expressed as

\[
\text{Cutting speed (C.S)} = \frac{\pi dn}{1000} \text{ m per sec}
\]

Where:

- ‘d’ - the diameter of the grinding wheel in mm, and
- ‘n’ - the speed of the grinding wheel in r.p.s.

4.7.2 Feed

Feed in a grinding process is the longitudinal movement of the work mounted on the table per revolution of the grinding wheel. It is expressed in mm per revolution.

The longitudinal feed during rough grinding is approximately 0.6 to 0.9 of the width of the wheel and 0.4 to 0.6 of the width of the wheel during finish grinding.

4.7.3 Depth of cut

The thickness of the metal layer removed from the work in one pass of the wheel is known as depth of cut. It is expressed in mm. Depth of cut is kept ranging from 0.005 to 0.04mm.

4.8 Surface finishing processes

In a workshop, metal parts are manufactured by performing different operations in lathe, shaping machine, milling machine, drilling machine or grinding machine. In order to enhance the quality of surfaces of these parts, several surface finishing processes are performed on them. If better finish is desired for looks, for accuracy, for wearing qualities or for better fits, one of the following processes is employed.

1. Lapping  
2. Honing  
3. Superfinishing

4. Polishing  
5. Buffing  
6. Scraping

7. Electroplating
4.8.1 Lapping

Lapping is the abrading process that is used to produce geometrically true surfaces, correct minor surface imperfections, improve dimensional accuracy to provide a very close fit between two surfaces in contact. Very thin layers of metal (0.005 to 0.01 mm) are removed in lapping. Machining can be done to the accuracy of less than 1 micron.

To perform lapping operation, lapping shoes and lapping mixture are needed. Laps may be made of almost any material soft enough to receive and retain the abrasive grains. They are made of soft cast iron, brass, copper or lead. It is made in different shapes. Abrasive powders such as emery, corundum, iron oxide and chromium oxide are mixed with oil or grease to make lapping mixture.

The face of the lap becomes charged with abrasive particles. Laps may be operated by hands or by machine. Cylindrical work may be lapped by rotating the work in a lathe and reciprocating the lap over the work. Flat surfaces may be lapped by holding the work against a rotating disc. Special lapping machines like vertical lapping machine, centreless lapping machine and abrasive belt lapping machines are also widely used.

4.8.2 Honing

Honing is the abrading process done mostly for finishing round holed produced by drilling, reaming or boring by means of bonded abrasive stones called ‘hones’. Honing is a machining process and is used to remove metal upto 0.25 mm. The surface roughness value can be maintained between 0.025 and 0.4 microns. So honing is used to correct some out of roundness, tapers, tool marks and axial distortion.

*Fig. 4.11 illustrates a honing toolhead.*

*Fig 4.11 Honing*
Honing stones are used for performing honing. Honing toolhead fitted with honing stones is fitted on spindles and rotated. The parts having holes to be honed are mounted on vises or suitable fixtures. The spindle is moved vertically to abrade the walls of the holes. A good quantity of coolant should be applied while honing.

Honing can be done on materials like plastic, silver, brass, aluminium, cast iron, steel and cemented carbide. Journal bearings supporting the crank shafts and long holes found in the barrels of guns are generally honed. The honing machines are of two types - Vertical & Horizontal.

4.8.3 Superfinishing

The process of superfinishing is an operation intended to produce an extremely high quality of surface finish. The surface roughness value can be maintained between 0.015 and 0.32 microns. A very thin layer of metal (0.005 mm to 0.02 mm) is removed by using very fine size of abrasives (Size of 400 to 600) in superfinishing. It can be done on both external and internal surfaces.

The grinding stones are made to reciprocate and the workpiece is made to rotate or reciprocate. A fine surface is obtained by admitting coolant mixed with kerosene. Using some special machines, superfinishing is performed on crankshaft, journal bearings and cam shafts.

4.8.4 Polishing

Polishing is a surface finishing operation performed by a polishing wheel for the purpose of removing metal to take out scratches, tool marks and other defects from rough surfaces. Polishing is performed only to provide better looks. Polishing wheels are made of leather, paper, canvas, felt or wool. The abrasive grains are setup sometimes on the faces of the wheel and work is held against it and rotated to give the desired finish.

4.8.5 Buffing

Buffing is used to give a much higher, reflective finish that cannot be obtained by polishing. Buffing wheels are made of felt, leather and pressed & glued layers of a variety of cloth. The abrasive used are iron oxide, chromium oxide, emery, etc. The abrasive is mixed with a binder. The binder is a paste consisting of wax mixed with grease, paraffin and turpentine. It is applied either on the buffing wheel or on the work. Buffing wheels are rotated against the work to get a superior finish.
4.8.6 Scraping

There will always be some minor imperfections on the machined surfaces. They are removed by an hand tool called scraper. There are three types of scrapers - flat, half-round and triangular. The part to be scraped is fitted in a vise and a thin layer of Persian blue is applied on the surface. A suitable scraper is selected and circular movements are made on the surface with it. Thin flakes of metal are removed. Persian blue is once again applied to check the flatness.

4.8.7 Electroplating

Electroplating is the process of applying metallic coatings on the surfaces of metal parts. It can be done on parts of non-metals also.

This is done for protection against corrosion or against wear and tear and for better appearance. It is also done to slightly increase the size of worn out parts and to make parts easy to solder. It may also be used to keep off selected areas on steel parts from being carburized during heat treatment.

Common plating materials are chromium, nickel, copper, zinc, cadmium, etc. The more precious metals like silver, gold, platinum, and radium are also applied for plating. Door handles and automobile parts are chromium plated for appearance. The method of plating a layer of zinc is known as galvanising.

![Fig 4.12 Electroplating](image)

**Fig 4.12 Electroplating**
Surfaces to be plated must be buffed smooth to eliminate scratches. The surface is cleaned by suitable cleaning solutions to remove all grease and dirt.

The four essential elements of plating process are the part to be plated (cathode), plating material (anode), electrolyte and direct current. The current leaves anode which is a bar of plating metal and migrates through the electrolyte to the cathode which is the part to be plated.

*Fig 4.12 shows the method of electroplating.*

**Safety precautions**

We should ensure that the work is held firmly and properly. The grinding wheel should be inspected and mounted on the spindle.

Proper work speed, wheel speed and table feed should be selected according to the nature of the work.

- Safety goggles should be worn by the operator.
- It should be checked whether the safety guards are fitted.
- The operator should not touch the rotating work or the grinding wheel.
- The operator should not wear loose shirts and neck tie.
- The work rest of a bench grinder should be placed close to the grinding wheel.
- The speed of the vitrified grinding wheels should not exceed 2800 meters per minute.

When new wheels are used, the wheel speed should be kept minimum.

If the job is held in a magnetic chuck, extra grips should be placed around the workpieces.
QUESTIONS

I.A. Choose the correct option

1. The accuracy obtained by precision grinding is
   a. 0.000025mm  b. 0.0025mm  
   c. 0.00125mm  d. 0.00625mm

2. The cutting tool with several thousands of cutting edges is
   a. lathe cutting tool  b. drill  
   c. grinding wheel  d. milling cutter

3. The heat generated during dry grinding will be
   a. 2000° C  b. 20° C  c. 1000° C  d. 1200° C

4. Bond used for making elastic grinding wheel is
   a. vitrified  b. silicate  c. shellac  d. resinoid

5. The grip with which the bond holds the abrasives is known as
   a. grain size  b. grade of the grinding wheel  
   c. structure of the grinding wheel  d. type of abrasive

I.B. Answer the following questions in one or two words

Name one artificial abrasive.

Name the grinding machine used for grinding jigs, fixtures and tools.

What is the name of the bond indicated by the letter ‘V’?

Answer the following questions in one or two sentences

What is grinding?

Name any four grinding machines.

What is centreless grinding?

What are the four types of surface grinders?

List any four operations performed in a grinding machine.

What are the effects of dry grinding?

Name any four types of bonds.

What is glazing?

What is loading?

What are the reasons for chattering?
III. Answer the following questions in about a page

List the types of rough and precision grinding machines.

Explain external centreless grinding with a diagram.

A grinding wheel is specified as follows \( w \ A \ 46 \ K \ 5 \ V \ 17 \). Explain the meaning of each symbol.

Explain ‘Dressing’ of a grinding wheel with a diagram.

Explain ‘Truing’ of a grinding wheel

Write short notes on

a. Lapping  
   b. Honing

IV. Answer the following questions in detail

Draw and explain a external cylindrical grinder.

Explain a surface grinder with a diagram.

Explain ‘mounting’ of a grinding wheel with a suitable diagram.

Write notes on

a. Precision grinding  
   b. Polishing  
   c. Buffing  
   d. Scraping
5. MILLING MACHINE

5.1 Introduction

Milling is a process of removing metal by feeding the work against a rotating multipoint cutter. The machine tool intended for this purpose is known as milling machine.

It is found in shops where tools and cutters are manufactured. The surface obtained by this machine tool is superior in quality and more accurate and precise.

Eli Whitney designed a complete milling machine in 1818. In the year 1861 Joseph Brown, a member of Brown and Sharp company developed the first universal milling machine.

5.2 Advantages and disadvantages of a milling machine

Advantages

The metal is removed at a faster rate as the cutter has got multiple cutting edges and rotates at a higher speed.

It is possible to perform machining by mounting more than one cutter at a time.

The table of the machine can be moved to an accuracy of 0.02mm.

It is very useful since various cutters and precise tools can be machined.

Special attachments can be mounted on the machine to perform operations that are performed in other machine tools.

The quality of the shop is enhanced with the presence of this machine.

Disadvantages

The cost of the milling machine is high.

As milling cutters cost high, the investment for procuring tools is more.

The production cost will increase if we carry out the operations performed in a shaper or a drilling machine with a milling machine.
5.3 Column and knee type milling machine

**Base**

It is made of cast iron and supports all the other parts of the machine tool. A vertical column is mounted upon the base. In some machines, the base serves as a reservoir for cutting fluid.

**Column**

It is mounted upon the base and is box shaped. It houses the mechanism for providing drive for the spindle. The front vertical face of the column is machined accurately to form dovetail guideways for the knee to move up and down. The top of the column holds an overhanging arm.

**Knee**

It slides up and down on the guideways of the column. An elevating screw mounted on the base obtains this movement. Saddle is mounted upon the knee and moves in a cross direction.

![Diagram of Horizontal milling machine](image)

**Fig 5.1** Horizontal milling machine (Pictorial view)
Saddle

It is mounted on the guideways of the knee and moves towards or away from the face of the column. This movement can be obtained either by power or by hand. The top of the saddle has guideways for the table movement.

Table

The table is moved longitudinally either by power or manually on the guideways of the saddle. The trip dogs placed on it control the movement of the table. The table of a universal milling machine can be swiveled horizontally to perform helical works. The top surface of the table has got ‘T’ – slots on which the workpieces or other work holding devices are mounted.

Spindle

It is located in the upper part of the column. It receives power from the motor through belt, gears and clutches. The front end of the spindle has got a taper hole into which the cutters are held with different cutter holding devices.

Fig 5.2 Horizontal milling machine
**Overhanging arm**

It supports the arbor from the top of the column. The arbor is supported by the bearing fitted within the arbor support. It is also useful while using some special attachments.

**Front brace**

It is an extra support fitted between the knee and the overhanging arm. It is slotted to allow the knee to be adjusted vertically.

**Arbor**

It supports the different types of cutters used in the machine. It is drawn into the taper hole of the spindle by a drawbolt. One or more cutters are mounted on the arbor by placing spacing collars between them. The arbor is supported by an arbor support. The arbor is provided with a Morse taper or self-releasing taper.

*A column and knee type milling machine is illustrated in Fig. 5.1 & 5.2*

![Vertical milling machine (Pictorial view)](image)
5.3.1 Vertical milling machine

It is very similar to a horizontal milling machine in construction as it has the same parts of base, column, knee, saddle and table. The spindle of the machine is positioned vertically. The cutters are mounted on the spindle. The spindle is rotated by the power obtained from the mechanism placed inside the column. Angular surfaces are machined by swiveling the spindle head.

*A vertical milling machine is illustrated in Fig. 5.3 & 5.4*

![Diagram of a vertical milling machine](image)

5.4 Types of milling machine

The milling machines are classified according to the general design of the machine.

- Column and knee type
  - Plain milling machine
  - Universal milling machine
  - Omniversal milling machine
  - Vertical milling machine
- Table type milling machine
- Planer type milling machine
- Special type milling machine
5.4.1 Column and knee type milling machine

The column of a column and knee type milling machine is mounted vertically upon the base. Knee is mounted on the accurately machined guideways of the column. It is designed to move up and down accurately. Saddle and table are mounted on the knee.

There are different types of column and knee type machines.

a) Plain milling machine

It is rigid and sturdy. Heavy workpieces are mounted and machined on the machine. The work mounted on the table is moved vertically, longitudinally and crosswise against the rotating cutter. The table cannot be rotated. It is also called as horizontal milling machine because the cutter rotates in horizontal plane.

b) Universal milling machine

The table of a universal milling machine can be swiveled by 45° on either side and so helical milling works can be performed. It is named so because it can be adapted for a very wide range of milling operations.

Various milling attachments like index head, vertical milling head, slot milling head and rotary table can be mounted. It can machine drills, reamers, gears, milling cutters with a very high degree of accuracy and so it finds an important place in a workshop.

c) Omniversal milling machine

In addition to the table movements obtained in a universal milling machine, the knee can be tilted to a required angle. It is useful for machining helical grooves, reamer and bevel gears. It is mostly used in tool room work.

d) Vertical milling machine

A spindle of a vertical milling machine is positioned at right angles to the table. The cutter is moved vertically or at an angle by swiveling the vertical head of the machine.

The machine is adapted for machining slots and flat surfaces by moving the table. By mounting end mills and face milling cutters on the spindle, vertical milling and internal milling are performed.
### 5.4.2 Differences between a plain milling machine and a universal milling machine

<table>
<thead>
<tr>
<th>Plain milling machine</th>
<th>Universal milling machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The table can be moved vertically, longitudinally and crosswise.</td>
<td>1. Apart from the three movements of a plain milling machine, it can be swiveled about 45°.</td>
</tr>
<tr>
<td>2. Helical milling works cannot be done as the table cannot be swiveled.</td>
<td>2. The table can be swiveled and helical milling and spiral milling can be performed.</td>
</tr>
<tr>
<td>3. As there are no special attachments, operations like gear cutting, slotting and</td>
<td>3. Special attachments like indexing head, rotary table, vertical milling attachment,</td>
</tr>
<tr>
<td>vertical milling cannot be performed.</td>
<td>slotting head are available with this machine. So spur gear, helical gear, bevel gear,</td>
</tr>
<tr>
<td>4. It is more rigid and suitable for machining on heavy and large workpieces and for</td>
<td>cutters and reamers can be machined.</td>
</tr>
<tr>
<td>simple milling operations.</td>
<td>4. It is meant for light workpieces. A wide range of operations can be performed in</td>
</tr>
<tr>
<td>5. The cost is less.</td>
<td>this machine. It is mainly used in tool rooms.</td>
</tr>
</tbody>
</table>

### 5.5 Size of a milling machine

The size of a milling machine is specified as follows:

- The size of the table (length and width)
- The maximum lengths of longitudinal, cross and vertical travel of the table.
- Number of spindle speeds, number of feeds
- Spindle nose taper
- Power required
- Nett weight of the machine
- The floor space required
- Type of the machine
5.6 Fundamental milling processes

The various milling processes may be grouped under two headings:

1. Peripheral milling
2. Face milling

5.6.1 Peripheral milling

The machining is performed by the cutting edges on the periphery of the milling cutter. It is classified under two headings

1. Up milling
2. Down milling

Up milling

In this method, the workpiece mounted on the table is fed against the direction of rotation of the milling cutter. The cutting force is minimum during the beginning of the cut and maximum at the end of cut. The thickness of chip is more at the end of the cut. As the cutting force is directed upwards, it tends to lift the workpiece from the fixtures. A difficulty is felt in pouring coolant on the cutting edge. Due to these reasons the quality of the surface obtained by this method is wavy. This process being safer is commonly used and sometimes called conventional milling.

Down milling

The workpiece mounted on the table is moved in the same direction as that of the rotation of the milling cutter. The cutting force is maximum at the beginning and minimum at the end of cut. The chip thickness is more at the beginning of the cut. The workpiece is not disturbed because of the bite of the cutter on the work. The coolant directly reaches to the cutting point. So the quality of surface finish obtained is high. Because of the backlash error between the feed screw of the table and the nut, vibration is set up on the workpiece.

Fig. 5.5 illustrates up milling & down milling.
5.6.2 Face milling and end milling

During face milling, the machining is performed by the peripheral cutting edges. The surface obtained by the processes is perpendicular to the axis of rotation of the cutter.

End milling is a process of the machining by milling cutters which have cutting edges both on the end face and on the periphery.

5.7 Work holding devices

For effective machining operations, the workpieces need to be properly and securely held on the machine table. The following are the usual methods of holding work on the table.

Large and irregular shaped workpieces are held on the milling machine table by ‘T’ – bolts and clamps.

‘V’ – blocks are used for holding cylindrical workpieces on the machine table in which keyways, slots and flats are to the machined. Angle plates are used to support the work when surfaces are to be milled at right angles to another machined surface.

![Fig 5.6 Plain vise](image)

Vises are commonly used for holding work on the table due to its quick loading and unloading arrangement. There are mainly three types of vises namely plain vise, swivel vise and universal vise. Different types of vises are shown in Fig. 5.6, 5.7 & 5.8.

![Fig 5.7 Swivel vise](image)
Milling fixtures are useful when large numbers of identical workpieces are to be machined. Workpieces are held easily, quickly and accurately by milling fixtures.

5.8 Cutter holding devices

Depending on the design of the cutter, there are several methods of supporting milling cutters on the machine spindle.

1) Arbor  
2) Collet  
3) Adapter  
4) Screwed on cutters

5.8.1 Arbor

Milling cutters with central holes are mounted and keyed on a shaft called arbor. There are three different types of arbor namely Pilot end arbor, ‘A’ type arbor and stub arbor.

The arbors are made with taper shanks for correct alignment with the machine spindle. The left side of the arbor is threaded internally to receive a drawbolt. This drawbolt connects the arbor with the spindle. A long key way is cut on the entire length of the arbor. Cutters are mounted at desired positions on the arbor by placing spacing collars between them. The spindle rotation is transmitted to the arbor and the cutter is rotated.

An arbor is illustrated in Fig. 5.9
5.8.2 Collet

It is a form of sleeve bushing used to hold arbors or cutters having a smaller shank than the spindle taper. Collets are connected to the spindle by a drawbolt and the rotary motion is transmitted to the cutters. *Fig. 5.10 shows a collet.*

5.8.3 Adapters

Milling cutters having shanks are generally mounted on adapters. The outside taper of the adapter conforms to the taper hole of the spindle. The shank of the cutter fits into the taper hole of the adapter. *An adapter is shown in Fig. 5.11*
5.8.4 Screwed arbor

The small cutters having threaded holes at the center are held by screwed arbors. It has a threaded nose at one end and a taper shank at the other end. The shank of the arbor is mounted on the spindle. *A Screwed arbor is illustrated in Fig. 5.12.*

5.9 Milling machine attachments

The milling machine attachments are intended for the purpose of developing the range of operations, versatility, production capacity and accuracy of machining process. The different milling machine attachments are:

- Vertical milling attachment
- Universal milling attachment
- High speed milling attachment
- Slotting attachment
- Rotary table attachment
- Indexing head attachment

**Vertical milling attachment**

A horizontal milling machine is converted into a vertical milling machine by the vertical milling attachment. Vertical milling attachment is mounted on the face of the column of the horizontal milling machine. The attachment along with the spindle can be swiveled to any angle for machining angular surfaces.

**5.9.2 Universal milling attachment**

By having the universal milling attachment, the spindle of the machine can be swiveled about two perpendicular axes. This arrangement permits the spindle axis to be swiveled at practically any angle to machine any angular surface of the work. This attachment is supported to the over arm to operate it at higher spindle speeds.
5.9.3 High speed milling attachment

This attachment is used to increase the regular spindle speeds by four to six times. Milling cutters of smaller diameters are operated efficiently at higher cutting speeds. This attachment is bolted to the face of the column and enables the cutter to be operated at speeds beyond the scope of the machine.

5.9.4 Slotting attachment

The rotary movement of the spindle is converted into reciprocating movement of the ram by a crank arrangement. This attachment makes the milling machine to be converted into a slotting machine by accepting a single point slotting tool. The tool is mounted on the ram and used for cutting internal or external keyways, splines etc., It can also be swiveled to machine angular surfaces.

5.9.5 Rotary table attachment

It is a special device bolted on top of the machine table to provide rotary motion to the workpiece in addition to the longitudinal, cross and vertical movements of the table. It consists of a circular table provided with ‘T’ – slots mounted on a graduated base. The driving mechanism of this attachment is made possible by a worm and worm gear.

5.9.6 Indexing head attachment

It is a special work holding device used for dividing the periphery of the work into any number of equal divisions. The work is held in a chuck of the dividing head spindle or supported between centers. It is also used in shaping machines and slotting machines. While machining gears, spirals, clutches and ratchets, this dividing head is used to divide the circumference of the work into any number of equal parts.

5.10 Standard milling cutters

There are different types of milling cutters used in a milling machine. A suitable milling cutter is selected according to the need. They are

- Plain milling cutter
- Side milling cutter
- Metal slitting saw
- Angle milling cutter
- End milling cutter
- ‘T’ – Slot milling cutter
- Fly cutter
- Formed cutter
5.10.1 Plain milling cutter

Plain milling cutters are cylindrical in shape and have teeth on the circumferential surface only. They are used for producing flat surfaces parallel to the axis of rotation of the spindle. The teeth of the cutter may be straight or helical according to the size. If the width of the cutter is more, it is called as slabbing cutter or cylindrical milling cutter. They have a central hole in order to be mounted on the arbor. Plain milling cutters have nicked teeth to break the chips into small pieces. Helical plain milling cutters are superior to a straight plain milling cutter. A plain milling cutter is illustrated in Fig. 5.13 & 5.14.

![Plain milling cutter and Side and face milling cutter](image)

Fig 5.13 Pictorial views of milling cutters

5.10.2 Side milling cutter

Side milling cutters have teeth on its periphery and also on one or both of its sides. They are intended for removing metal from the sides of the workpiece. There are different types of side milling cutters namely face and side milling cutter, half side milling cutter, staggered teeth side milling cutter, and interlocked side milling cutter. Machining is performed by selecting a proper milling cutter. A side milling cutter is illustrated in Fig. 5.13 & 5.15.

![Side milling cutter](image)

Fig 5.14 Plain milling cutter
5.10.3 Metal slitting saw

It is intended for cutting narrow, deep slots and for parting off operation. The teeth are cut on the circumference of the cutter. The width of the cutter is limited. The outside diameter of the cutter will be up to 200mm and width of the cutter ranges from 0.75mm to 7mm. The side of the cutter is relieved so that the side may not rub against the work.

* A metal slitting saw is illustrated in Fig. 5.16.
5.10.4 Angle milling cutter

The teeth of the angle milling cutter are not parallel to the axis but are at an angle to it. By using angle milling cutter, inclined surfaces, bevels and helical grooves are machined. There are two types of angle milling cutter – Single angle milling cutter and double angle milling cutter. *Fig. 5.17 shows a single angle milling cutter.*

![Fig 5.17 Angle milling cutter (Single)](image)

5.10.5 ‘T’ – Slot milling cutter

It is a special form of end mills intended for machining ‘T’- slots. It looks like a side milling cutter with a shank. The cutters have cutting teeth on the periphery as well as on both sides of the cutter. *Fig. 5.18 shows a ‘T’ – Slot milling cutter.*

5.10.6 End mill

These cutters have cutting teeth on the end as well as on the periphery of the cutter. It is made of two parts – body and shank. The shanks of the cutter may be straight or taper. If the cutter doesn’t have a shank it is called shell end milling cutter. These cutters are useful in machining long narrow slots, holes and flat surfaces. *A End mill is illustrated in Fig. 5.19.*

![Fig 5.18 ‘T’ slot milling cutter](image)
5.10.7 Fly cutter

Fly cutter is the simplest form of cutter. It consists of a single point cutting tool attached to the end of the arbor. The cutting edge may be formed to reproduce a contoured surface. They are used when standard cutters are not available. The work is done very slowly because of a single cutting edge. A fly cutter is shown in Fig. 5.20.

5.10.8 Formed cutter

Formed cutters have irregular profiles on their cutting edges to produce required outlines on the work. Concave and convex milling cutters are used to produce convex and concave surfaces respectively. Using gear milling cutters, gears are machined. Corner round milling cutters are used for cutting a radius on the edges of the work. With the help of thread milling cutters threads are milled to a specific form and size. Tap and reamer cutters are used for producing grooves or flutes in taps and reamers.
5.11 Elements of a plain milling cutter

The main parts and angles of a plain milling cutter as shown in Fig. 5.21 are described below:

**Body of cutter**: It is the part of the cutter left after exclusion of the teeth.

**Face**: The portion of the teeth next to the cutting edge is known as face.

**Land**: The relieved back portion of the tooth adjacent to the cutting edge. It is relieved to avoid interference between the surface being machined and the cutter.

**Outside diameter**: The diameter of the circle passing through the peripheral cutting edges.

**Central hole**: It refers to the hole present at the centre of the cutter. A keyway is cut inside the hole.
Cutter angles

**Relief angle:** It is angle the between the land of the tooth and the tangent to the outside diameter of the cutter at the cutting edge of the particular tooth. (approx 7.5 °)

**Primary clearance angle:** It is the angle between the back of the tooth and the tangent drawn to the outside diameter of the cutter at the cutting edge. (approx 15 °)

**Secondary clearance angle:** It is the angle formed by the secondary clearance surface and the tangent to the periphery of the cutter at the cutting edge.

**Rake angle:** The angle measured in the diametral plane between the face of the tooth and a radial line passing through the cutting edge of the tooth. The rake angles may be positive, negative or zero. If the face and the tooth body are on the same side of the radial line, the rake angle between the radial line and the tooth face is positive. The tooth face and tooth body may be on opposite sides of the radial line. Then the rake angle is negative. If the radial line and the tooth face coincide in the diameter plane the rake angle is zero.

5.12 Milling cutter materials

The milling cutters are generally made of the following materials.

1. Tool steel
2. High speed steel (HSS)
3. High carbon steel (HCS)
4. Cemented carbide
5. Stellite

In general shop work, the high speed steel cutters are most widely used.

5.13 Milling machine operations

The following operations are performed using suitable milling cutters.

1. Plain milling
2. Face milling
3. Side milling
4. Straddle milling
5. Angular milling
6. Gang milling
7. Form milling
8. End milling
9. Flute milling
10. Keyway milling
11. Drilling & reaming
12. Boring
13. Gear cutting
14. Thread milling
15. Cam milling
5.13.1 Plain milling

It is the operation of production of a flat surface parallel to the axis of rotation of the cutter. It is also called as slab milling. Plain milling cutters and slab milling cutters are used to perform this operation. *Fig. 5.23 shows plain milling operation.*

5.13.2 Face milling

The face milling is the operation performed by the face milling cutter rotated about an axis at right angles to the work surface. End mills and side & face milling cutter are also used at times to perform this operation. The depth of cut is provided to the table. *Fig. 5.23 shows face milling operation.*
5.13.3 Side milling

Side milling is the operation of machining a vertical surface on the side of a workpiece by using a side milling cutter.

5.13.4 Straddle milling

It is the operation of production of two vertical surfaces on both sides of the work by two side milling cutters mounted on the same arbor. By using suitable spacing collars, the distance between the two cutters is adjusted correctly. The straddle milling is commonly used to produce square or hexagonal surfaces.

Fig. 5.24 shows straddle milling operation.
5.13.5 Angular milling

Production of an angular surface on a workpiece other than at right angles to the axis of the milling machine spindle is known as angular milling. Example of angular milling is the production of the ‘V’ blocks. Fig. 5.25 shows angular milling operation.

5.13.6 Gang milling

It is the operation of machining several surfaces of work simultaneously by feeding the table against a number of cutters (either of same type or of different type) mounted on the arbor of the machine. This method saves much of machining time and mostly used in production work. Fig. 5.26 shows gang milling operation.

5.13.7 Form milling

The form milling is the operation of production of irregular contours by using form cutters. Machining convex and concave surfaces and gear cutting are some examples of form milling. Fig. 5.27 shows form milling operation.
5.13.8 End milling

It is the operation of producing a flat surface which may be vertical, horizontal or at an angle to the table surface. The end milling is performed by a cutter known as an end mill. End milling is mostly performed in a vertical milling machine.

*Fig. 5.28 shows end milling operation.*

5.13.9 Flute milling

Flute milling is performed by selecting a suitable cutter in a milling machine. The flutes found on the drills, reamers and taps are machined by this method.

5.13.10 Keyway milling

The operation of production of keyways, grooves and slots of different shapes and sizes can be performed in a milling machine by using a plain milling cutter, a metal slitting saw, an end mill or by a side milling cutter.

5.13.11 Drilling and reaming

The operation of drilling and reaming are performed in a milling machine by mounting drills and reamers into the spindle of the machine.

5.13.12 Boring

A single point cutting tool is mounted on the arbor to perform boring. By adjusting the single point cutting tool radially, different diameters of bores are machined.

5.13.13 Gear cutting

Gear cutting operation is performed in a milling machine by using a form cutter. The work is held between centers on a universal dividing head. A proper gear cutter is selected and the teeth are cut by DP, module method.
5.13.14 Thread milling

This operation is performed in a special thread milling machine by rotating both the work and the cutter. Several cuts are made to cut the threads to their depth.

5.13.15 Cam milling

Cam milling is the operation of producing cams in a milling machine with the use of a universal dividing head and a vertical milling attachment. It is performed by end mills on the cam blank.

5.14 Cutting speed, feed and depth of cut

5.14.1 Cutting speed

It is the distance travelled by a point on the cutting edge of the milling cutter to remove metal in time duration of one minute. It is expressed in meters per minute.

\[
\text{Cutting Speed} = \frac{\pi DN}{1000} \text{ meter / minute}
\]

Where:
- \(D\) = The diameter of the milling cutter in mm
- \(N\) = Spindle speed in rpm

The cutting speed depends upon the material to be machined, the cutter material, depth of cut, feed, type of operation and the coolant used.

**Example:** Calculate the cutting speed to perform milling with a cutter of diameter 60mm and spindle speed of 250rpm.

**Solution:**

Given: Diameter of cutter \((D)\) = 60 mm
Spindle speed \((N)\) = 250 rpm

\[
\text{Cutting Speed} = \frac{\pi DN}{1000} \text{ meter / minute}
\]

\[
= \frac{22 \times 60 \times 250}{7 \times 1000}
\]

\[
= 47.14 \text{ metre / minute}
\]
5.14.2 Feed

The feed in a milling machine is defined as the distance the workpiece advances under the cutter. Feed can be expressed in three different methods:

**Feed per tooth:** It is the distance the work advances in the time between engagements by the two successive teeth. It is expressed in mm per tooth.

**Feed per cutter revolution:** It is the distance the work advances in the time when the cutter turns through one complete revolution. It is expressed in mm per revolution of the cutter.

**Feed per minute:** It is the distance the work advances in one minute. It is expressed in mm per minute.

The feed in a milling machine depends on the material to be machined, cutter material, depth of cut, cutting speed, type of operation and the rigidity of the machine.

5.14.3 Depth of cut

The depth of cut is the thickness of the material removed in one pass of the work below the cutter. It is expressed in mm.

5.15 Indexing head

Indexing is the method of dividing the periphery of a piece of work into any number of equal parts. The attachment used for performing indexing is known as indexing head.

The indexing operation can be adapted for cutting gears, ratchet wheels, keyways, fluted drills, taps and reamers. The indexing head serves as an attachment for holding and indexing the work in doing the above tasks. There are three different types of indexing heads namely

- Plain or simple dividing head
- Universal dividing head
- Optical dividing head.

**Construction of indexing head**

*The construction of a universal dividing head as shown in Fig. 5.29 & 5.30 is explained below:*

**Base**

The base of the indexing head is fitted in the ‘T’ – slots of the milling machine table. It supports all the other parts of dividing head.
Spindle

The spindle is situated at the centre of the dividing head. It has a taper hole to receive a live center. The spindle is supported on a swiveling block, which makes the spindle to be tilted through any angle from 5° below horizontal to 10° beyond vertical. A worm wheel is mounted on the spindle. While doing direct or rapid indexing, the index plate is directly fitted on the front end of the spindle nose.

Worm shaft

It is situated at right angles to the main spindle of the dividing head. A single threaded worm is mounted on the worm shaft, which meshes with the worm wheel. An index plate is fitted on the front end of the worm shaft and with the help of a handle the worm shaft can be rotated to a predetermined amount.

Fig 5.29 Construction of a index head
Index plate

It is mounted on the front end of the worm shaft. It is a circular disk having different numbers of equally spaced holes arranged in concentric circles. The crank is positioned in the required hole circle and rotated through a calculated amount while indexing. The sector arm is used to eliminate the necessity of counting the holes on the index plate each time the index crank is moved.

![Index plate diagram](image)

**Fig 5.30 Index head**

Driven shaft

It is parallel to the spindle and perpendicular to the worm shaft.

Dead center

The work is held between the center of the spindle and the dead center. It can be made to slide and positioned at the required location.

5.15.2 Working principle of dividing head

When the crank is rotated with help of a handle through the required number of holes in the index plate, the work is rotated to required amount. This is possible because of the worm and worm wheel mechanism.

A gear train is arranged between the main spindle and the driven shaft when indexing is done by differential indexing method. The work is rotated as usual when the handle is rotated. At the same time, the index plate is also made to rotate a small amount through the gear train. When indexing is by this differential indexing method, the index plate is released from the lock pin.
5.16 Indexing methods

There are several methods of indexing and they are

- Direct or rapid indexing
- Plain or simple indexing
- Compound indexing
- Differential indexing
- Angular indexing

Safety precautions

Before operating the milling machine, the operator should know how to operate various controls of the machine. It should be ensured that the workpiece is held rigidly on the milling machine table. The cutter should not be in contact with the work even before the machining is commenced. The spindle speed of the machine should not be altered when the machine is in operation. When the power of the machine is ‘ON’, the arbor nut should not be removed or tightened. The operator should keep his body away from the rotating cutter. No steps should be taken to measure the workpiece while the cutter is cutting or revolving near the workpiece. When the machine is in operation, safety guards should be placed in their positions to prevent coolant and metal chips from spilling out.

The metal chips should be removed with suitable brushes and not with bare hands. The operator should seek assistance from others while handling special attachments and heavy workpieces. The operator should always be present in person at the machine tool when the machine is in operation.

The machine tool should always be started and stopped by the operator himself. Dangers can be averted by handling the cutters with sharp cutting edges with great care. The machine tool should be kept clean. Milling cutters and measuring instruments should not be placed on the machine.

The attention of the operator should always be focussed on the task only. When troubles happen in the machine, they should be corrected with the assistance of proper technicians. In general, safety should be ensured to the operator, the workpiece and the cutting tool.